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PROJECTION EXPOSURE METHOD AND SYSTEM
[投影露光方法及び装置]

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Specification

Projection Exposure Method and System

Field of the Invention

The present invention relates to a projection exposure method and system, which are used for transferring a mask pattern to a photosensitive substrate in a lithography process, wherein devices such as semiconductor elements, imaging elements (for example, CCD), liquid crystal display elements and thin-film magnetic heads are manufactured. More particularly, the present invention relates to a projection exposure method and system, which use a liquid immersion method.

Background of the Invention

When a semiconductor element or the like is manufactured, a projection exposure system is used. This projection exposure system transfers an image of a reticle pattern, which is a mask, onto each of the shot areas on a resist-coated wafer (or glass plate), which is a photosensitive substrate, through a projection optical system. Conventionally, as the projection exposure system, a reduced projection type, step and repeat projection exposure system (stepper) is widely used. Recently, much attention is paid to a step and scan projection exposure system, wherein a reticle and a wafer are scanned in synchronization with each other to conduct an exposure.

The resolution of a projection optical system, which is mounted on a projection exposure system, is increased as the exposure wavelength used is decreased or the numerical aperture of the projection optical system is increased. Therefore, as the size of the integrated circuit is miniaturized, the exposure wavelength used in the projection exposure system is decreased each passing year and thus the numerical aperture of the projection exposure system is increased. Currently, the mainstream exposure wavelength is 248 nm excimer lasers. In addition, a short wavelength, that is, 193 nm excimer lasers, is being put to practical use.

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Furthermore, when an exposure is conducted, the depth of focus (DOF) becomes important in a manner similar to the resolution. Resolution (R) and depth of focus (δ) are expressed by the following formulas:

$$R = k_1 \cdot \lambda / NA \quad \ldots (1)$$

$$\delta = k_2 \cdot \lambda / NA^2 \quad \ldots (2)$$

Here, (λ) represents an exposure wavelength, (NA) represents a numerical aperture of the projection exposure system, (k_1) and (k_2)

[1] Numbers in the margin display pagination in the foreign text.

represent process coefficients. Based on formulas (1) and (2), it is found that, when exposure wavelength (λ) is decreased and numerical aperture (NA) is increased so as to increase resolution (R), depth of focus (δ) narrows. In a conventional projection exposure system, an exposure is conducted by focusing the surface of a wafer on the surface of an image of the projection exposure system by automatic focus. In this case, it is preferable that depth of focus (δ) is widened to some extent. Therefore, conventionally, there are approaches such as phase shift reticle fabrication method, off-axis illumination method and multilayer resist method, which attempt to substantially widen the depth of focus.

As described above, according to the conventional projection exposure system, due to a decrease in wavelength of exposure light and an increase in numerical aperture of the projection optical system, the depth of focus narrows. To respond to higher integration of semiconductor integrated circuits, there are attempts to further decrease the exposure wavelength. In this case, the depth of focus becomes too narrow and the margin at exposure may be decreased.

To solve the above described problem, a liquid immersion method is proposed as the method wherein the exposure wavelength is substantially decreased and at the same time the depth of focus is widened. According to this method, water or liquid such as an organic solvent is filled between the bottom surface of a projection optical system and the surface of a wafer and, since a wavelength of exposure light in liquid becomes 1/n times [(n) represents a refractive index of the liquid, normally, 1.2 to 1.6] longer than the wavelength in air, it is possible to improve the resolution and widen the depth of focus by about (n) times.

If the above described liquid immersion method is simply applied to a step and repeat projection exposure system, when the exposure of a shot area is completed and the wafer makes a step movement to the subsequent shot area, the liquid is discharged from between the projection optical system and the wafer.

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Therefore, it is necessary to feed another liquid. In addition, it is difficult to recover the liquid. Furthermore, when the liquid immersion method is applied to a step and scan projection exposure system, since an exposure is conducted while the wafer is moved, the liquid must be filled between the projection optical system and the wafer even while the wafer is moved.

To solve the above described problems, the present invention attempts to provide a projection exposure method capable of keeping a liquid filled between a projection optical system and a wafer even

while the projection optical system and the wafer are relatively moved when a liquid immersion method is used. In addition, the present invention attempts to provide a projection exposure system capable of implementing said projection exposure method, a method for effectively manufacturing said projection exposure system, and a method for manufacturing a highly functional device using said projection exposure method.

Disclosure of the Invention

The 1st projection exposure method, according to the present invention, wherein mask (R) is illuminated by an exposure beam, the pattern of mask (R) is transferred onto substrate (W) through projection optical system (PL), is characterized in that, when substrate (W) is moved in a predetermined direction, predetermined liquid (7) is supplied along the moving direction of substrate (W) so as to fill the portion between the surface of substrate (W) and the tip end of optical element (4) on the side of substrate (W) in projection optical system (PL).

According to the 1st projection exposure method of the present invention, since a liquid is filled between the tip end of projection optical system (PL) and substrate (W) by using a liquid immersion method, it is possible to increase the wavelength of exposure light on the surface of the substrate to 1/n times [(n) represents a refractive index of the liquid] longer than the wavelength in air, and widen the depth of focus by (n) times compared with that of air. In addition, when the substrate is moved in a predetermined direction, the liquid is supplied along the moving direction of the substrate. /4
Therefore, it is possible to fill the liquid between the tip end of the projection optical system and the surface of the substrate even when the substrate is moved. In addition, when a foreign object is attached onto the substrate, the liquid can wash away said foreign object from the substrate.

The 1st projection exposure system, according to the present invention, wherein mask (R) is illuminated by an exposure beam, the pattern of mask (R) is transferred onto substrate (W) through projection optical system (PL), is characterized in that said projection exposure system comprises: substrate stages (9) and (10) for holding and moving substrate (W); liquid supply device (5) for supplying predetermined liquid (7) along a predetermined direction via supply pipe (21a) so as to fill the portion between the surface of substrate (W) and the tip end of optical element (4) on the side of substrate (W) in projection optical system (PL); and liquid recovery device (6) for recovering liquid (7) from the surface of substrate (W) via discharge pipes (23a) and (23b), which are arranged

together with supply pipe (21a) so as to surround an area illuminated by the exposure beam in said predetermined direction, and liquid (7) is supplied and recovered upon moving substrate (W) along said predetermined direction by driving substrate stages (9) and (10).

According to the above described 1^{st} projection exposure system of the present invention, by using the pipes, it is possible to implement the 1^{st} projection exposure method of the present invention.

In addition, it is preferable to arrange a second set of supply pipe (22a) and discharge pipes (24a) and (24b) in a position, which is obtained by rotating the position of the first set of supply pipe (21a) and discharge pipes (23a) and (23b) by 180 degrees. In this case, when substrate (W) is moved in a direction opposite to said predetermined position, by using the second set of pipes, it is possible to more stably keep filling the liquid between the tip end of projection optical system (PL) and the surface of substrate (W).

Furthermore, when the projection exposure system is the scanning exposure type, wherein mask (R) and substrate (W) are moved in synchronization with each other relative to projection optical system (PL) so as to conduct an exposure, it is preferable that said predetermined direction is the scanning direction of substrate (W) during the scanning exposure process.

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In this case, it is possible to continuously keep filling liquid (7) between the surface of substrate (W) and the tip end of optical element (4) on the side of substrate (W) in projection optical system (PL) even during the scanning exposure process, and thus conduct an exposure with a high degree of accuracy and stability.

In addition, it is preferable to arrange a set or two sets of supply pipe (27a) and discharge pipes (29a) and (29b) in a position, which corresponds to the position of the set of supply pipe (21a) and discharge pipes (23a) and(23b). In this case, it is possible to continuously keep filling liquid (7) between the surface of substrate (W) and the tip end of projection optical system (PL) even when substrate (W) makes a step movement in the direction opposite to said predetermined direction.

Furthermore, it is preferable to create control system (14) capable of adjusting the supply amount and recovery amount of liquid (7) in accordance with the moving speed of the substrate stages. In other words, for example, when the moving speed is fast, the supply amount is increased and, when the moving speed is slow, the supply amount is decreased so as to constantly keep filling the liquid between

the surface of substrate (W) and the tip end of projection optical system (PL) without wasting it.

In addition, liquid (7), which is supplied to the surface of substrate (W), is, for example, pure water or fluorinated inactive liquid, wherein the temperature is adjusted to a predetermined temperature. In this case, pure water can be easily obtained in a semiconductor manufacturing plant and does little harm to the environment. Furthermore, since the liquid (7) is adjusted to a predetermined temperature, it is possible to adjust the temperature of the surface of the substrate and thus prevent thermal expansion of substrate (W), which is caused by heat generated during the exposure process. It is obvious that the transmittance of the liquid to the exposure beam is preferably high.

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However, even when the transmittance is low, since the working distance of the projection optical system is short, the absorption of the exposure beam is extremely small.

The method, according to the present invention, for manufacturing a projection exposure system, is characterized in that said projection exposure system is made by mounting, at prescribed positions, illumination system (1), wherein an exposure beam is illuminated to mask (R), projection optical system (PL), wherein an image of a pattern of mask (R) is transferred onto substrate (W), substrate stages (9) and (10) for holding and moving substrate (W), liquid supply device (5) for supplying predetermined liquid (7) along a predetermined direction via supply pipe (21a) so as to fill the portion between the surface of substrate (W) and the tip end of optical element (4) on the side of substrate (W) in projection optical system (PL), and liquid recovery device (6) for recovering liquid (7) from the surface of substrate (W) via discharge pipes (23a) and (23b), which are arranged together with supply pipe (21a) so as to surround an area illuminated by the exposure beam in said predetermined direction.

In addition, the 1st method, according to the present invention, for manufacturing a device, wherein said device is manufactured by using the 1st projection exposure method of the present invention, is characterized in that said method comprises an exposure process, wherein mask (R) is illuminated by an exposure beam, the pattern of mask (R) is transferred onto substrate (W) of said device through projection optical system (PL), and when substrate (W) is moved in a predetermined direction during said exposure process, predetermined liquid (7) is supplied along the moving direction of substrate (W) so as to fill the portion between the surface of substrate (W) and the tip end of optical element (4) on the side of substrate (W) in

projection optical system (PL). According to the above described method, wherein a liquid immersion method is used, it is possible to manufacture a highly functional device.

The 2nd projection exposure method, according to the present invention, wherein mask (R) is illuminated by an exposure beam and substrate (W) is illuminated by said exposure beam through projection optical system (PL), is characterized in that liquid (7) is supplied so as to fill the portion between said projection optical system and the substrate and at the same time the direction of said liquid is changed in accordance with the direction of movement of said substrate.

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According to the 2nd projection exposure method of the present invention, since a liquid is filled between projection optical system (PL) and substrate (W) by using a liquid immersion method, it is possible to increase the wavelength of exposure light on the surface of the substrate to 1/n times [(n) represents a refractive index of the liquid] longer than the wavelength in air, and widen the depth of focus by (n) times compared with that of air. In addition, by changing the direction of said liquid in accordance with the direction of movement of said substrate, even if the direction of movement of said substrate is frequently changed, it is possible to keep filling the liquid between the projection optical system and the substrate.

In addition, in the case wherein the supply speed of liquid (7) is divided into the 1st component with a moving direction of said substrate and the 2nd component with a direction perpendicular to said moving direction, when the 1st component has a direction opposite to the moving direction of substrate (W), it is preferable that liquid (7) is supplied in a manner wherein the amount of said liquid is equal to or less than a predetermined allowable value. Since the component of velocity of the liquid, which has the direction opposite to the moving direction of substrate (W), is decreased, it is possible to smoothly supply the liquid.

Furthermore, it is more preferable that liquid (7) is supplied nearly along the moving direction of substrate (W).

Moreover, when substrate (W) is exposed by a step and repeat method, or a step and scan method, it is preferable that liquid (7) is supplied nearly along the stepping direction of substrate (W).

In addition, it is preferable that mask (R) and substrate (W) are moved relative to said exposure beam and the substrate is scanned and exposed by said exposure beam so that liquid (7) is supplied nearly

along the scanning direction of said substrate during the scanning exposure process.

Here, it is preferable that the flow rate of liquid (7) is adjusted in accordance with a moving speed of substrate (W).

The 2nd method, according to the present invention, for manufacturing a device comprises a lithography process having a process for transferring a device pattern onto substrate (W) by using the 2nd projection exposure method of the present invention.

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According to the above described method, wherein a liquid immersion method is used, it is possible to manufacture a highly functional device.

The 2nd projection exposure system, according to the present invention, wherein mask (R) is illuminated by an exposure beam and substrate (W) is illuminated by said exposure beam through a projection optical system (PL), is characterized in that said projection exposure system comprises liquid supply device (5), wherein liquid (7) is supplied so as to fill the portion between said projection optical system and the substrate and at the same time the direction of said liquid is changed in accordance with the direction of movement of said substrate.

According to the above described 2nd projection exposure system, it is possible to implement the 2nd projection exposure method of the present invention. In addition, even if the direction of movement of said substrate is frequently changed, it is possible to keep filling the liquid between the projection optical system and the substrate.

In addition, it is preferable that said projection exposure system further comprises stage system [RST, (9) to (11)] for moving mask (R) and substrate (W) relative to said exposure beam so that liquid supply device (5) supplies liquid (7) nearly along the moving direction of substrate (W) while the substrate is scanned and exposed.

Furthermore, the above described projection exposure system further comprises liquid recovery device (6) for recovering liquid (7), which is supplied between projection optical system (PL) and substrate (W).

Moreover, it is preferable that supply opening (21a) of liquid supply device (5) and recovery openings (23a) and (23b) of liquid recovery device (6) are arranged so as to surround an area illuminated by said exposure beam.

Brief Description of the Drawings

Figure 1 is a view illustrating the structure of the projection exposure system, which is used in Embodiment 1 of the present invention. Figure 2 is a view illustrating the positional relationship between /9 tip end (4A) of lens (4) of projection optical system (PL) and its discharge and inflow nozzles in an X direction. Figure 3 is a view illustrating the positional relationship between tip end (4A) of lens (4) of projection optical system (PL) of Figure 1 and its discharge and inflow nozzles for supplying and recovering a liquid in a Y direction. Figure 4 is an enlarged view illustrating the state wherein liquid (7) is supplied and recovered from between lens (4) and wafer (W) of Figure 1. Figure 5 is a front view illustrating the lower end of projection optical system (PLA), liquid supply device (5) and liquid recovery device (6) of the projection exposure system, which is used in Embodiment 2 of the present invention. Figure 6 is a view illustrating the positional relationship between tip end (32A) of lens (32) of projection optical system (PLA) of Figure 5 and its discharge and inflow nozzles in an X direction. Figure 7 is a view illustrating the positional relationship between tip end (32A) of lens (32) of projection optical system (PLA) of Figure 5 and its discharge and inflow nozzles for supplying and recovering a liquid in a Y direction.

Preferred Embodiment of the Invention

Next, an example of the preferred embodiment of the present invention will be described by referring to Figures 1 to 4. According to this example, the present invention is applied to the case wherein an exposure is conducted in a step and repeat projection exposure system.

Figure 1 is a view illustrating the structure of the projection exposure system according to the present embodiment. As shown in Figure 1, a pattern formed on reticle (R) is illuminated by exposure light (IL). Said exposure light is made from ultraviolet pulsed light with a wavelength of 248 nm, which comes from illumination optical system (1) comprising KrF excimer laser light source, which is an exposure light source, an optical integrator (homogenizer), a field stop and a condenser lens and the like. The pattern of reticle (R) is reduced in size and projected in an exposure area on wafer (W), which is coated with a photo resist, at predetermined projection magnification (β) [(β) may be 1/4 or 1/5] through double-sided [or on wafer (W) side] telecentric projection optical system (PL). /10 Here, as exposure light (IL), it is possible to use ArF excimer laser light (wavelength: 193 nm), F_2 laser light (wavelength: 157 nm) or i-line (wavelength: 365 nm) of a mercury lamp and the like. Next,

the present embodiment will be described by using a Z-axis, which is parallel to light axis (AX) of projection optical system (PL), a Y-axis, which is perpendicular to the paper surface of Figure 1 and drawn on a flat surface perpendicular to a Z-axis, and an X-axis, which is parallel to the paper surface of Figure 1.

Reticle (R) is held on reticle stage (RST). A mechanism, which slowly moving reticle (R) in an X direction, a Y direction and the direction of rotation, is mounted on reticle stage (RST). The two-dimensional position and rotational angle of reticle stage (RST) are measured in real time by a laser interferometer (not shown in the figure). Based on the measured values, main control system (14) determines the position of reticle (R).

In the meantime, wafer (W) is fixed to Z stage (9), which controls the focus position (position in a Z direction) and tilt angle of wafer (W), through wafer holder (not shown in the figure). Z stage (9) is fixed to XY stage (10). XY stage (10) is placed on base (11) and moves along a XY flat surface, which is substantially parallel to the surface of an image of projection optical system (PL). Z stage (9) controls the focus position (position in a Z direction) and tilt angle of wafer (W) and focuses the surface of wafer (W) on the surface of an image of projection optical system (PL) by automatic focus and automatic leveling. XY stage (10) determines the position of wafer (W) in the X direction and Y direction. The two-dimensional position and rotational angle of Z stage (9) are measured in real time as the position of moving mirror (12) by laser interferometer (13). Based on the measurement results, control information is sent from main control system (14) to wafer stage driving system (15). Based on said information, wafer stage driving system (15) controls the operation of Z stage (9) and XY stage (10). When an exposure is conducted, each of the shot areas on wafer (W) sequentially makes a step movement to an exposure position so as to expose an image of a pattern of reticle (R). This operation is repeated by a step and repeat method.

According to the present embodiment, the exposure wavelength is substantially decreased so as to improve the resolution and a liquid immersion method is used to substantially widen the depth of focus.
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For this purpose, at least while the pattern image of reticle (R) is transferred onto wafer (W), predetermined liquid (7) is filled between the surface of wafer (W) and the tip end (lower surface) of lens (4) on the wafer side of projection optical system (PL). Projection optical system (PL) comprises mirror cylinder (3) for storing other optical systems and lens (4) and has a structure wherein only lens (4) comes into contact with liquid (7). As a result, it

is possible to prevent corrosion of mirror cylinder (3), which is made from metal.

Here, projection optical system (PL) is made from a plurality of optical elements including lens (4). Lens (4) is detachably (replaceably) fixed to the lowest part of mirror cylinder (3). According to the present embodiment, an optical element, which is the closest to wafer (W), that is, the one, which comes into contact with liquid (7), is made from a lens. However, the material of said optical element is not limited to a lens. Instead, it is possible to use an optical plate (for example, plane parallel plate), which is used for adjusting optical properties of projection optical system (PL) such as aberration (for example, spherical aberration or coma aberration). In addition, since the surface of the optical element, which comes into contact with liquid (7), is contaminated due to scattering of particles generated from the resist by illumination of exposure light or attachment of impurities in liquid (7), it is necessary to periodically replace the optical element. However, if a lens is used as the optical element, which comes into contact with liquid (7), the cost of the replacement part is increased and the time required for replacing it is increased. As a result, the maintenance cost (running cost) is increased and the throughput is decreased. To solve this problem, a plane parallel plate, which is less expensive than lens (4), may be used as the optical element, which comes into contact with liquid (7). In this case, even if the plane parallel plate is contaminated with substances (for example, silicon group organic substances), which decrease the transmittance of projection optical system (PL), illumination intensity of exposure light on wafer (W) and homogeneity of the illumination distribution during the conveyance, assembly or adjustment process of the projection exposure system, it can be replaced with a new one immediately before liquid (7) is supplied. Therefore, in this case, compared with the case wherein a lens is used as the optical element, which comes into contact with liquid (7), it is possible to decrease the replacement cost.

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In addition, according to the present embodiment, pure water is used as liquid (7). Pure water can be easily obtained in large amounts in a semiconductor manufacturing plant and does not have an adverse effect on a photo resist and optical lens on the wafer. Furthermore, pure water does little harm to the environment and contains an extremely small amount of impurities. Therefore, it is also expected that pure water can clean the surface of the wafer and that of lens (4).

Since the refractive index of pure water (water) to exposure light, which has a wavelength of about 250 nm, is almost 1.4, the

wavelength (248 nm) of KrF excimer laser light is shortened by 1/n times on wafer (W), that is, to about 177 nm. As a result, it is possible to increase the resolution. Furthermore, since the depth of focus is increased by about (n) times, that is, about 1.4 times, compared with that of air, when the same depth of focus as that of air is ensured, it is possible to increase the numerical aperture of projection exposure system (PL) and thus improve the resolution.

Liquid (7) is supplied onto wafer (W) by liquid supply device (5), which comprises a tank for said liquid, a pressure pump and a temperature control device, through predetermined discharge nozzles in a manner wherein the temperature of said liquid is controlled. Said liquid is recovered from wafer (W) by liquid recovery device (6), which comprises a tank for said liquid and suction pump, through predetermined nozzles. The temperature of liquid (7) is set at a temperature similar to that of a chamber wherein the projection exposure system of the present invention is stored. Discharge nozzle (21a), which has a narrower tip end, and two inflow nozzles (23a) and (23b) (see Figure 2), which has wider tip ends, are disposed so as to hold lens (4) at the tip end of projection optical system (PL) in an X direction. Discharge nozzle (21a) is connected to liquid supply device (5) through supply pipe (21) while inflow nozzles (23a) and (23b) are connected to liquid recovery device (6) through recovery pipe (23). In addition, a set of nozzles are arranged in a position, which is obtained by rotating the position of the set of discharge nozzle (21a) and inflow nozzles (23a) and (23b) by 180 degrees, and two sets of discharge nozzles and inflow nozzles are disposed so as to hold lens (4) at the tip end in a Y direction.

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Figure 2 is a view illustrating the positional relationship among tip end (4A) of lens (4) of projection optical system (PL), wafer (W) and two sets of discharge and inflow nozzles, which are disposed so as to hold said lens at tip end (4A) in an X direction. In Figure 2, discharge nozzle (21a) is arranged in a + X direction of tip end (4A) and inflow nozzles (23a) and (23b) are arranged in a - X direction. In addition, inflow nozzles (23a) and (23b) are arranged in a manner wherein they pass through the center of tip end (4A) and spread out in a fan-like form relative to an axis parallel to the X axis. Another set of discharge nozzle (22a) and inflow nozzles (24a) and (24b) are arranged in a position, which is obtained by rotating the position of said set of discharge nozzle (21a) and inflow nozzles (23a) and (23b) by 180 degrees. Discharge nozzle (22a) is connected to liquid supply device (5) through supply pipe (22) while inflow nozzles (24a) and (24b) are connected to liquid recovery device (6) through recovery pipe (24).

Figure 3 is a view illustrating the positional relationship between tip end (4A) of lens (4) of projection optical system (PL) of Figure 1 and two sets of discharge nozzles and inflow nozzles, which are disposed so as to hold said lens at tip end (4A) in a Y direction. In Figure 3, discharge nozzle (27a) is arranged in a + Y direction of tip end (4A) and inflow nozzles (29a) and (29b) are arranged in a - Y direction. Discharge nozzle (27a) is connected to liquid supply device (5) through supply pipe (27) while inflow nozzles (29a) and (29b) are connected to liquid recovery device (6) through recovery pipe (29). In addition, another set of discharge nozzle (28a) and inflow nozzles (30a) and (30b) are arranged in a position, which is obtained by rotating the position of said set of discharge nozzle (27a) and inflow nozzles (29a) and (29b) by 180 degrees. Discharge nozzle (28a) is connected to liquid supply device (5) through supply pipe (28) while inflow nozzles (30a) and (30b) are connected to liquid recovery device (6) through recovery pipe (30). Liquid supply device (5) supplies a temperature-controlled liquid between tip end (4A) of lens (4) and wafer (W) through at least one of supply pipes (21), (22), (27) and (28) while liquid recovery device (6) recovers said liquid through at least one of recovery pipes (23), (24), (29) and (30).

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Next, the method for supplying and recovering liquid (7) will be described.

In Figure 2, when wafer (W) makes a step movement in the direction (- X direction) of arrow (25A), which is expressed by a solid line, liquid supply device (5) supplies liquid (7) between tip end (4A) of lens (4) and wafer (W) through supply pipe (21) and discharge nozzle (21a). Liquid recovery device (6) recovers liquid (7) from wafer (W) through recovery pipe (23) and inflow nozzles (23a) and (23b). Here, liquid (7) flows in the direction (- X direction) of arrow (25B) on wafer (W) and the portion between wafer (W) and lens (4) is stably filled by liquid (7).

In the meantime, when wafer (W) makes a step movement in the direction (+ X direction) of arrow (26A), which is expressed by an alternate long and two short dash line, liquid supply device (5) supplies liquid (7) between tip end (4A) of lens (4) and wafer (W) through supply pipe (22) and discharge nozzle (22a). Liquid recovery device (6) recovers liquid (7) from wafer (W) through recovery pipe (24) and inflow nozzles (24a) and (24b). Here, liquid (7) flows in the direction (+ X direction) of arrow (26B) on wafer (W) and the portion between wafer (W) and lens (4) is filled by liquid (7). In this manner, according to the projection exposure system of the present embodiment, two sets of discharge nozzles and inflow nozzles are reversed in an X direction with respect to each other. Therefore,

when wafer (W) is moved either in a + X direction or - X direction, it is possible to stably keep filling liquid (7) between wafer (W) and lens (4).

In addition, since liquid (7) flows on wafer (W), even when a foreign object (including particles scattering from the resist) is attached to wafer (W), liquid (7) can wash it away. Furthermore, since liquid (7) is adjusted to a predetermined temperature by liquid supply device (5), the temperature of the surface of wafer (W) is adjusted. As a result, it is possible to prevent phenomenon such as a decrease in alignment accuracy by thermal expansion of the wafer, which is caused by heat generated during the exposure process. Therefore, even if there is a temporal difference between alignment and exposure such as EGA (enhanced global alignment), it is possible to prevent alignment accuracy from decreasing due to thermal expansion of a wafer.

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In addition, according to the projection exposure system of the present embodiment, liquid (7) flows in the same direction as the one wherein wafer (W) is moved. Therefore, it is possible to recover the liquid, which absorbs foreign objects or heat, without accumulating it on an exposure area, which is situated immediately below tip end (4A) of lens (4).

Furthermore, when wafer (W) makes a step movement in a Y direction, liquid (7) is supplied and recovered in the Y direction.

In other words, when the wafer makes a step movement in the direction (- Y direction) of arrow (31A) of Figure 3, which is expressed by a solid line, liquid supply device (5) supplies the liquid through supply pipe (27) and discharge nozzle (27a). Liquid recovery device (6) recovers the liquid through recovery pipe (29) and inflow nozzles (29a) and (29b). The liquid flows in the direction (- Y direction) of arrow (31B) on an exposure area, which is immediately below tip end (4A) of lens (4). In addition, when the wafer makes a step movement in a + Y direction, the liquid is supplied and recovered through supply pipe (28), discharge nozzle (28a), recovery pipe (30) and inflow nozzles (30a) and (30b). The liquid flows in a + Y direction on an exposure area, which is immediately below tip end (4A). In this manner, in a manner similar to the case wherein wafer (W) is moved in an X direction, even when wafer (W) is moved either in a + Y direction or - Y direction, it is possible to fill liquid (7) between wafer (W) and tip end (4A) of lens (4).

Here, in addition to the nozzles for supplying and recovering liquid (7) in an X direction or Y direction, nozzles for supplying and recovering liquid (7) in an oblique direction may be created.

Next, the method for controlling the supply amount and recovery amount of liquid (7) will be described.

Figure 4 is a view illustrating the state wherein liquid (7) is supplied and recovered from between lens (4) of projection optical system (PL) and wafer (W). In Figure 4, wafer (W) moves in the direction (- X direction) of arrow (25A) while liquid (7), which is supplied through discharge nozzle (21a), flows in the direction (- X direction) of arrow (25B) and recovered through inflow nozzles (23a) and (23b). /16
To keep a constant amount of liquid (7), which exists between lens (4) and wafer (W) even during the movement of wafer (W), according to the present embodiment, supply amount [Vi(m^3/s)] and recovery amount [Vo(m^3/s)] are equalized. In addition, supply amount (Vi) and recovery amount (Vo) of liquid (7) are adjusted so as to be proportional to moving speed (v) of XY stage (10) [wafer (W)]. In other words, main control system (14) determines supply amount (Vi) and recovery amount (Vo) of liquid (7) based on the following formula:

$$Vi = Vo = D \cdot v \cdot d \ldots (3)$$

Here, as shown in Figure 1, (D) represents a diameter (m) of the tip end of lens (4), (v) represents moving speed (m/s) of XY stage (10), and (d) represents working distance (m) of projection optical system (PL). Since speed (v) at a step movement of XY stage (10) is determined by main control system (14) and (D) and (d) are preliminarily input, by adjusting supply amount (Vi) and recovery amount (Vo) of liquid (7) based on formula (3), it is possible to constantly fill liquid (7) between lens (4) and wafer (W) of Figure 4.

Here, to stably fill liquid (7) between projection optical system and wafer (W), it is preferable to decrease working distance (d) of projection optical system (PL) as much as possible. However, if working distance (d) is too short, the surface of wafer (W) may come into contact with lens (4) and thus some margin must be created. For example, working distance (d) may be set at about 2 mm. Since working distance (d) is short, even the transmittance of liquid (7) to an exposure light is somewhat low, the absorption of the exposure light is extremely small.

Next, Embodiment 2 of the present invention will be described by referring to Figures 5 to 7. According to the present embodiment, the present invention is applied to the case wherein an exposure is conducted by a step and scan projection exposure system.

Figure 5 is a front view illustrating the lower part of projection optical system (PLA), liquid supply device (5) and liquid

recovery device (6) of the projection exposure system according to the present embodiment.

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In Figure 5, wherein the same codes are assigned to the parts corresponding to those of Figure 4, lens (32) of the lowermost part of mirror cylinder (3A) of projection optical system (PLA) has tip end (32A), which is a part necessary for a scanning exposure and shaped in an elongated rectangle in a Y direction (non-scanning direction). During the scanning exposure process, a pattern image of a part of a reticle is projected on the rectangular exposure area, which is immediately below tip end (32A) and the reticle (not shown in the figure) moves in a - X direction (or a + X direction) at speed (V) relative to projection optical system (PLA). In synchronization with the movement of the reticle, wafer (W) moves in a + X direction (or - X direction) at speed (β·V) [(β) represents a projection magnification] through XY stage (10). After an exposure of a shot area is completed, the subsequent shot area moves onto the scanning start position by stepping of wafer (W). From then on, an exposure of each of the shot areas is sequentially conducted by the step and scan method.

According to the present embodiment, during the scanning exposure process, liquid (7) is filled between lens (32) and the surface of wafer (W) by using a liquid immersion method. Liquid (7) is supplied and recovered by liquid supply device (5) and liquid recovery device (6).

Figure 6 is a view illustrating the positional relationship between tip end (32A) of lens (32) of projection optical system (PLA) and the discharge and inflow nozzles, which supply and recover liquid (7) in the X direction. In Figure 6, tip end (32A) of lens (32) is shaped in an elongated rectangle in the Y direction. Here, three discharge nozzles (21a) to (21c) are disposed so as to hold lens (32) at tip end (32A) of projection optical system (PLA) in a + X direction while two inflow nozzles (23a) and (23b) are arranged in a - X direction.

Discharge nozzles (21a) to (21c) are connected to liquid supply device (5) through supply pipe (21) while inflow nozzles (23a) and (23b) are connected to liquid recovery device (6) through recovery pipe (23). In addition, discharge nozzles (22a) to (22c) and inflow nozzles (24a) and (24b) are created in a position, which is obtained by rotating the position of discharge nozzles (21a) to (21c) and inflow nozzles (23a) and (23b) by about 180 degrees.

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Discharge nozzles (21a) to (21c) and inflow nozzles (24a) and (24b) are alternately arranged in the Y direction. Discharge nozzles (22a)

to (22c) and inflow nozzles (23a) and (23b) are alternately arranged in the Y direction. Discharge nozzles (22a) to (22c) are connected to liquid supply device (5) through supply pipe (22) while inflow nozzles (24a) and (24b) are connected to liquid recovery device (6) through recovery pipe (24).

When a scanning exposure is conducted by moving wafer (W) in a scanning direction (- X direction), which is shown by an arrow of a solid line, liquid (7) is supplied and recovered by liquid supply device (5) and liquid recovery device (6) by using supply pipe (21), discharge nozzles (21a) to (21c), recovery pipe (23) and inflow nozzles (23a) and (23b). Here, liquid (7) flows in a - X direction so as to fill the portion between lens (32) and wafer (W). In addition, when a scanning exposure is conducted by moving wafer (W) in a direction (+ X direction), which is shown by an arrow of an alternate long and two short dash line, liquid (7) is supplied and recovered by using supply pipe (22), discharge nozzles (22a) to (22c), recovery pipe (24) and inflow nozzles (24a) and (24b). Here, liquid (7) flows in a + X direction so as to fill the portion between lens (32) and wafer (W). By switching the flow direction of liquid (7) in accordance with the scanning direction, even when wafer (W) is scanned in a + X direction or - X direction, it is possible to fill liquid (7) between wafer (W) and tip end (32A) of lens (32) and thus increase the resolution and widen the depth of focus.

In addition, supply amount [$Vi(m^3/s)$] and recovery amount [$Vo(m^3/s)$] are determined by the following formula:

$$Vi = Vo = D_{SY} \cdot v \cdot d \ldots (4)$$

Here, (D_{SY}) represents a length (m) of tip end (32A) of lens (32) in an X direction. In this manner, even during the scanning exposure process, it is possible to stably fill liquid (7) between lens (32) and wafer (W).

Here, the number and shape of nozzles are not limited to specific ones. For example, liquid (7) may be supplied to and recovered from a long side of tip end (32A) through two sets of nozzles.

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In this case, discharge nozzles and inflow nozzles may be arranged one above the other so as to supply and recover liquid (7) to and from + X direction and - X direction.

In addition, when wafer (W) makes a step movement in a Y direction, in a manner similar to Embodiment 1, liquid (7) is supplied and recovered in the Y direction.

Figure 7 is a view illustrating the positional relationship between tip end (32A) of lens (32) of projection optical system (PLA) and its discharge and inflow nozzles for supplying and recovering a liquid in the Y direction. In Figure 7, when the wafer makes a step movement in a non-scanning direction (- Y direction), which is perpendicular to the scanning direction, liquid (7) is supplied and recovered by using discharge nozzle (27a), inflow nozzles (29a) and (29b), which are arranged in the Y direction. When the wafer makes a step movement in a + Y direction, liquid (7) is supplied and recovered by using discharge nozzle (28a), inflow nozzles (30a) and (30b), which are arranged in the Y direction. In addition, supply amount [Vi (m^3/s)] and recovery amount [Vo (m^3/s)] are determined by the following formula:

$$Vi = Vo = D_{SX} \cdot v \cdot d \quad \ldots (5)$$

Here, (D_{SX}) represents a length (m) of tip end (32A) of lens (32) in a Y direction. In a manner similar to Embodiment 1, even when wafer (W) makes a step movement in the Y direction, by adjusting the supply amount of liquid (7) in accordance with moving speed (v) of wafer (W), it is possible to continuously keep filling liquid (7) between lens (32) and the wafer.

As described above, when wafer (W) is moved, by supplying liquid (7) in a direction corresponding to the moving direction of the wafer, it is possible to continuously keep filling liquid (7) between wafer (W) and the tip end of projection optical system (PL).

Here, the liquid, which is used as liquid (7) in the above described embodiments, is not limited to pure water. Instead, it is possible to use a liquid, which has transmittance to an exposure light and a refractive index, which is as high as possible, and is stable (for example, cedar oil) with a photo resist, which is coated on the projection optical system and the wafer surface.

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In addition, as liquid (7), it is possible to use a fluorine group inactive liquid, which has high transmittance to an exposure light and is safe to the environment. As an example of the above described fluorine group inactive liquid, it is possible to use Florinate (brand name, made by 3M USA Co.). The fluorine group inactive liquid is excellent in the cooling effect.

Furthermore, liquid (7), which is recovered according to each of the above described embodiments, may be recycled. In this case, it is preferable that a filter, which removes impurities from recovered liquid (7), is installed in the liquid recovery device or a recovery pipe and the like.

Moreover, the range of an area, wherein liquid (7) flows, may be set so as to cover the entire projection area (area, which is illuminated by an exposure light) of a pattern image of the reticle. The size of said area may be discretionally selected. Considering ease of control of the flow rate and volume, it is preferable to slightly increase said area relative to the exposure area of each of the above described embodiments and keep it as small as possible. Here, since it is difficult to recover all of the supplied liquid through the inflow nozzles, a dividing wall, which surrounds the wafer, may be formed and a pipe for recovering liquid within said dividing wall may be installed so as not to make the liquid leak from the Z stage.

In addition, according to each of the above described embodiments, liquid (7) flows along the moving direction of wafer (W) [XY stage (10)]. However, the flow direction of liquid (7) does not always correspond to the moving direction of the wafer. In other words, the flow direction of liquid (7) may intersect with the moving direction of the wafer. For example, when wafer (W) moves in a + X direction, liquid (7) may flow along a direction, wherein the component of velocity of a - X direction of liquid (7) is zero, or a predetermined allowable value or less. As a result, when the wafer is exposed by using a step and repeat method or step and scan method (both include a step and switch method), even if the moving direction of the wafer frequently changes in a short time (for example, several hundreds of ms), it is possible to control the flow direction of the liquid in accordance with the change and thus keep filling the liquid between the projection optical system and the wafer.

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In addition, according to the step and scan projection exposure system, movement of the XY stage is controlled so as to prevent the component of velocity in the scanning and non-scanning directions of the XY stage from being zero during the movement of the wafer between each of the shot areas. In other words, movement of the XY stage is controlled as follows: the stepping process (movement in a non-scanning direction) of the XY stage is started after completion of a scanning exposure of a shot area, e.g., during deceleration of the XY stage (before the component of velocity in the non-scanning direction becomes zero), and then acceleration of the XY stage is started before completion of said stepping process (before the component of velocity of the non-scanning direction becomes zero, for example, during deceleration of the XY stage) so as to scan and expose the subsequent shot area. Even in the above described case, it is possible to control the flow direction of the liquid in accordance with the moving direction of the wafer and thus keep filling the liquid between the projection optical system and the wafer.

Here, the use of the projection exposure system of the present embodiment is not limited to the projection exposure system for manufacturing semiconductor devices. Instead, it may be used in the projection exposure system for liquid crystals, wherein a pattern of a liquid crystal display element is exposed on a square glass plate, or the projection exposure system for manufacturing thin film magnetic heads.

In addition, the reticle or mask, which is used in an exposure system for manufacturing devices wherein semiconductor elements and the like are manufactured, may be manufactured by an exposure system using far-ultraviolet light or vacuum-ultraviolet light. The projection exposure system, according to each of the above described embodiments, can be favorably used in the photolithography process wherein said reticle or mask is manufactured.

Furthermore, a DFB semiconductor laser, which is used as an exposure light, or an infrared or visible-range single wavelength laser, which is oscillated from a fiber laser, is amplified by a fiber amplifier, wherein erbium (Er) [both erbium and ytterbium (Yb)] is doped, and converted to an ultraviolet light by using a nonlinear optical crystal. The resultant high harmonic may be used.

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In addition, projection optical system (PL) may be the dioptric system, catoptric system or catadioptric system. As an example of the catadioptric projection optical system, it is possible to use the optical system disclosed in US patent No. 5,788,229, wherein a plurality of dioptric elements and two catoptrics elements (at least one of them is a concave mirror) are arranged in an optical axis, which extends in a straight line without being bent. According to the exposure system, which has the catadioptric system disclosed in said US patent, the optical element, which is the closest to the wafer, that is, the one, which comes into contact with the liquid, becomes a catoptrics element. Here, as far as the national laws of the designated nations or the selected nations, according to the present international application, allow, the disclosure of the above described US patent is incorporated herein as a part of the present application.

Furthermore, an illumination optical system, which comprises a plurality of lenses, and a projection optical system are mounted on the exposure system for conducting an optical adjustment, and at the same time, a reticle stage and wafer stage, which comprise a large number of mechanical parts, are mounted on the exposure system, wires and pipes are connected, a pipe work (supply pipe and discharge nozzles and the like) for supplying and recovering the liquid is installed and a total adjustment (electricity adjustment and operation check

and the like) is made thereby manufacturing the projection exposure system of the present embodiment. Here, it is preferable to manufacture the projection exposure system in a clean room wherein the temperature and cleanness are controlled.

The semiconductor device is manufactured after going through the steps of: designing the function and performance of the device; manufacturing the reticle based on said step; producing a wafer from a silicon material; exposing a pattern of the reticle on the wafer by the projection exposure system of the above described embodiment; assembling the device (including the singulation process, bonding process and packaging process); and inspecting it.

Here, the present invention is not limited to the above described embodiments. The present invention may have various structures without departing from the scope of the invention. Furthermore, Japanese patent application No. 10-79263, which is filed on March 26, 1998 and comprises a specification, Claims, drawings and an abstract, is fully incorporated herein.

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Industrial Applicability

According to the 1st or 2nd projection exposure method of the present invention, since it uses a liquid immersion method, it is possible to widen the depth of focus of a pattern image of a mask by about (n) time [(n) represents a refractive index of the liquid] relative to the depth of focus in air and thus stably transfer an ultrafine pattern with a high resolution. As a result, it is possible to mass-produce a high-density semiconductor device and the like in good yield. In addition, when the substrate of the semiconductor device is moved along a predetermined direction, the liquid is supplied along the moving direction of the substrate so as to fill the portion between the surface of the substrate and the tip end of the optical element on the substrate side of the projection optical system. As a result, even when the substrate is moved, the liquid is filled between the surface of the substrate and the tip end of the projection optical system and the liquid immersion method can be used. Furthermore, when a foreign object is attached onto the substrate, the liquid can wash away said foreign object from the substrate. As a result, it is possible to improve the yield of the final product.

According to the 1st or 2nd projection exposure system of the present invention, it is possible to implement the 1st or 2nd projection exposure method. In addition, when the supply amount and recovery amount (flow rate) of the liquid in accordance with the moving speed of the substrate stage, even when the moving speed of the stage is changed, it is possible to keep a constant amount of the liquid, which

is filled between the surface of the substrate and the tip end of the projection optical system.

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Scope of Patent Claims

1. A projection exposure method, wherein a mask is illuminated by an exposure beam, the pattern of said mask is transferred onto a substrate through a projection optical system, characterized in that, when said substrate is moved in a predetermined direction, a predetermined liquid is supplied along the moving direction of said substrate so as to fill the portion between the surface of said substrate and the tip end of an optical element on the side of said substrate in said projection optical system.

2. A projection exposure system, wherein a mask is illuminated by an exposure beam, the pattern of said mask is transferred onto a substrate through a projection optical system, characterized in that said projection exposure system comprises: substrate stages for holding and moving said substrate; a liquid supply device for supplying a predetermined liquid along a predetermined direction via a supply pipe so as to fill the portion between the surface of said substrate and the tip end of an optical element on the side of said substrate in said projection optical system; and a liquid recovery device for recovering said liquid from the surface of said substrate via discharge pipes, which are arranged together with said supply pipe so as to surround an area illuminated by the exposure beam in said predetermined direction, and said liquid is supplied and recovered upon moving said substrate along said predetermined direction by driving said substrate stages.

3. The projection exposure system as set forth in Claim 2, characterized in that a second set of a supply pipe and discharge pipes are arranged in a position, which is obtained by rotating the position of the first set of said supply pipe and said discharge pipes by 180 degrees.

4. The projection exposure system as set forth in Claim 2 or 3, characterized in that said projection exposure system is the scanning exposure type, wherein a mask and a substrate are moved in synchronization with each other relative to said projection optical system so as to conduct an exposure, and said predetermined direction is the scanning direction of said substrate during the scanning exposure process.

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5. The projection exposure system as set forth in Claim 2, 3 or 4, characterized in that a set of a supply pipe and discharge pipes, or two sets of said pipes, which are reversed with each other, are

arranged in a position, which corresponds to the position of the set of said supply pipe and said discharge pipes.

6. The projection exposure system as set forth in one of Claims 2 to 5, characterized in that said projection exposure system comprises a control system capable of adjusting the supply amount and recovery amount of said liquid in accordance with moving speed of said substrate stages.

7. The projection exposure system as set forth in one of Claims 2 to 6, characterized in that said liquid, which is supplied to the surface of said substrate, is pure water or fluorinated inactive liquid, wherein the temperature is adjusted to a predetermined temperature.

8. A method for manufacturing a projection exposure system, characterized in that said projection exposure system is made by mounting, at prescribed positions, an illumination system, wherein an exposure beam is illuminated to a mask, a projection optical system, wherein an image of a pattern of said mask is transferred onto a substrate, substrate stages for holding and moving said substrate, a liquid supply device for supplying a predetermined liquid along a predetermined direction via a supply pipe so as to fill the portion between the surface of said substrate and the tip end of an optical element on the side of said substrate in said projection optical system, and a liquid recovery device for recovering said liquid from the surface of said substrate via discharge pipes, which are arranged together with said supply pipe so as to surround an area illuminated by the exposure beam in said predetermined direction.

9. A method for manufacturing a device, wherein said device is manufactured by using the projection exposure method as set forth in Claim 1, characterized in that said method comprises an exposure process, wherein a mask is illuminated by an exposure beam, the pattern of said mask is transferred onto a substrate of said device through a projection optical system, and when said substrate is moved in a predetermined direction during said exposure process, a predetermined liquid is supplied along the moving direction of said substrate so as to fill the portion between the surface of said substrate and the tip end of an optical element on the side of said substrate in said projection optical system.

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10. A projection exposure method, wherein a mask is illuminated by an exposure beam and a substrate is illuminated by said exposure beam through a projection optical system, characterized in that a liquid is supplied so as to fill the portion between said projection optical system and said substrate and at the same time the direction of said

liquid is changed in accordance with the direction of movement of said substrate.

11. The projection exposure method as set forth in Claim 10, characterized in that, in the case wherein the supply speed of said liquid is divided into the 1^{st} component with a moving direction of said substrate and the 2^{nd} component with a direction perpendicular to said moving direction, when the 1^{st} component has a direction opposite to the moving direction of said substrate, said liquid is supplied in a manner wherein the amount of said liquid is equal to or less than a predetermined allowable value.

12. The projection exposure method as set forth in Claim 10, characterized in that said liquid is supplied nearly along the moving direction of said substrate.

13. The projection exposure method as set forth in Claim 12, characterized in that said substrate is exposed by a step and repeat method or a step and scan method and said liquid is supplied nearly along the stepping direction of said substrate.

14. The projection exposure method as set forth in Claim 12 or 13, characterized in that said mask and said substrate are moved relative to said exposure beam and the substrate is scanned and exposed by said exposure beam so that said liquid is supplied nearly along the scanning direction of said substrate during the scanning exposure process.

15. The projection exposure method as set forth in one of Claims 10 to 14, characterized in that the flow rate of said liquid is adjusted in accordance with a moving speed of said substrate.

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16. A method for manufacturing a device, characterized in that said method comprises a lithography process having a process for transferring a device pattern onto a substrate by using the projection exposure method as set forth in one of Claims 10 to 15.

17. A projection exposure system, wherein a mask is illuminated by an exposure beam and a substrate is illuminated by said exposure beam through a projection optical system, characterized in that said projection exposure system comprises a liquid supply device, wherein a liquid is supplied so as to fill the portion between said projection optical system and said substrate and at the same time the direction of said liquid is changed in accordance with the direction of movement of said substrate.

18. The projection exposure system as set forth in Claim 17, characterized in that, in the case wherein the supply speed of said liquid is divided into the 1st component with a moving direction of said substrate and the 2nd component with a direction perpendicular to said moving direction, when the 1st component has a direction opposite to the moving direction of said substrate, said liquid is supplied in a manner wherein the amount of said liquid is equal to or less than a predetermined allowable value.

19. The projection exposure system as set forth in Claim 18 characterized in that said substrate is exposed by a step and repeat method or a step and scan method and said liquid supply device supplies said liquid nearly along the stepping direction of said substrate.

20. The projection exposure system as set forth in one of Claims 17 to 19, characterized in that said projection exposure system further comprises a stage system for moving said mask and said substrate relative to said exposure beam so that said liquid supply device supplies said liquid nearly along the moving direction of said substrate while said substrate is scanned and exposed.

21. The projection exposure system as set forth in one of Claims 17 to 20, characterized in that said projection exposure system further comprises a liquid recovery device for recovering a liquid, which is supplied between said projection optical system and said substrate.

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22. The projection exposure system as set forth in Claim 21, characterized in that a supply opening of said liquid supply device and recovery openings of said liquid recovery device are arranged so as to surround an area illuminated by said exposure beam.

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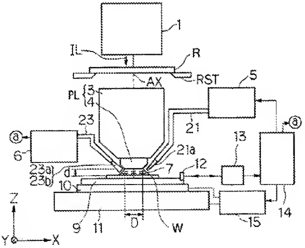
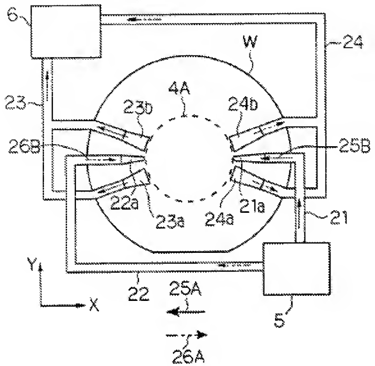
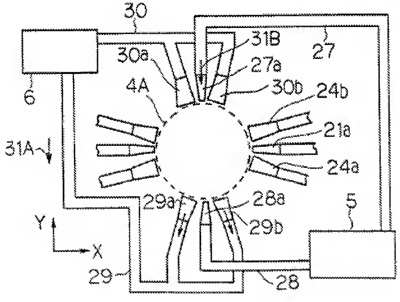
[Figure 1]



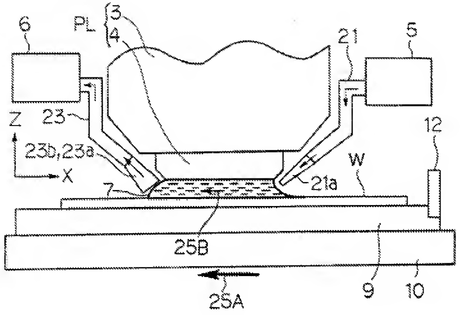
[Figure 2]



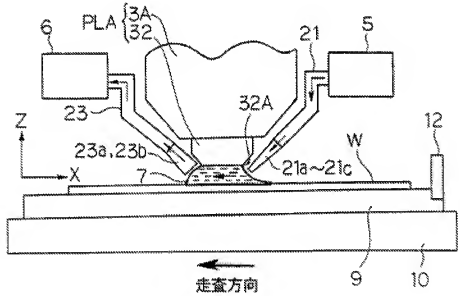
[Figure 3]



[Figure 4]

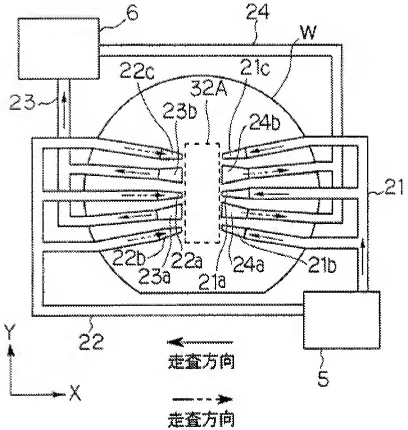


[Figure 5]



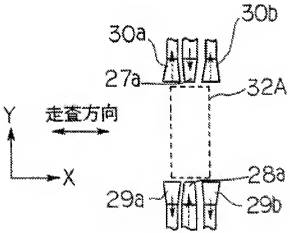
(Bottom Arrow): Scanning Direction

[Figure 6]



(Left Facing Arrow): Scanning Direction
(Right Facing Arrow): Scanning Direction

[Figure 7]



(Arrow on Left Side): Scanning Direction